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# A determination of electroweak parameters at HERA

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Using the deep inelastic  $e^+p$  charged and neutral current scattering cross sections previously published, a combined electroweak and QCD analysis is performed to determine electroweak parameters accounting for their correlation with parton distributions. The data used have been collected by the H1 experiment in 1994-2000 and correspond to an integrated luminosity of  $117.2 \text{ pb}^{-1}$ . A first measurement at HERA is made of the light quark weak couplings to the  $Z^0$  boson. An improved measurement is obtained of the  $W$  propagator mass in charged current  $ep$  scattering. The weak mixing angle  $\sin^2\theta_W$  is determined in the on-mass-shell renormalization scheme.

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## 1. The experimental facts and analysis strategies

In the first phase of HERA operation (HERA-I) with the unpolarized  $e^\pm$  beam colliding with the proton beam, the H1 experiment has collected three major data samples of  $e^+p$  in years from 1994 to 1997 at a center-of-mass energy of 301 GeV,  $e^-p$  in 1998-1999 and  $e^+p$  in 1999-2000 at 319 GeV. The corresponding integrated luminosities are 35.6 pb<sup>-1</sup>, 16.4 pb<sup>-1</sup> and 65.2 pb<sup>-1</sup>, respectively. These data have been used to measure neutral current (NC) and charged current (CC) cross sections covering more than 4 orders of magnitude in both  $Q^2$ , the negative four-momentum transfer squared, and Bjorken  $x$ . The large kinematic coverage and the different flavor sensitivity of the  $e^\pm p$  NC and CC cross section data have enabled 5 sets of parton distribution functions (PDF) to be determined simultaneously in a previous QCD analysis [1]. These five PDF sets are the gluon, up-type and down-type quarks and their anti-quarks distributions.

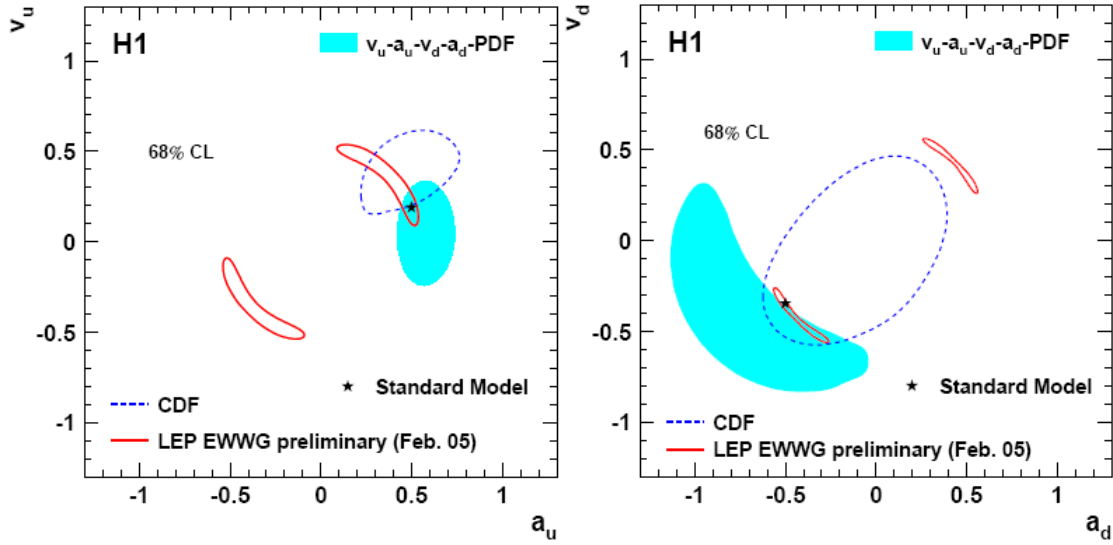
The inclusive NC and CC cross sections are not only sensitive to PDFs but also to electroweak (EW) parameters. Indeed, the NC cross sections at high  $Q^2$  depend on up- and down-type quark couplings to the  $Z^0$  boson,  $a_q$  and  $v_q$  ( $q=u, d$ ), via structure functions, whereas the shape of the CC cross sections as a function of  $Q^2$  is controlled by the propagator mass ( $M_{prop}$ ) of the  $W$  boson. It is thus natural to extend the QCD analysis of [1] into a combined EW-PDF analysis so that EW parameters can be determined together with the PDFs taking properly into account the small but non-negligible correlation between them.

This is precisely the strategy chosen in [2,3], namely using the same parameterization forms for the five PDF sets for the QCD part. The QCD analysis is performed using the DGLAP evolution equations [4] at next-to-leading order in the modified minimal subtraction renormalization scheme. All quarks are taken as massless. Several combined EW-PDF fits are performed either in a model independent way (fits  $a_u-v_u-a_d-v_d$ -PDF and  $G-M_{prop}$ -PDF) or within the Standard Model (SM, fits  $M_W$ -PDF and  $m_t$ -PDF).

## 2. First results on light quark couplings to the $Z^0$ boson at HERA

The sensitivity on the quark couplings at HERA stems from the  $\gamma Z$  interference and  $Z^0$  exchange contributions in NC interactions at high  $Q^2$ . The results of the combined  $a_u-v_u-a_d-v_d$ -PDF fit are shown in Fig.1 and compared with similar results obtained recently by the CDF experiment [5] and combined LEP experiments [6]. The HERA determination has comparable precision to that from the Tevatron. These determinations are sensitive to  $u$  and  $d$  quarks separately, contrary to other measurements of the light quark- $Z^0$  couplings in  $\nu N$  scattering [7] and atomic parity violation [8] on heavy nuclei. They also resolve any sign ambiguity and the ambiguities between  $v_q$  and  $a_q$  ( $q=u,d$ ) of the determinations based on observables measured at the  $Z^0$  resonance [6].

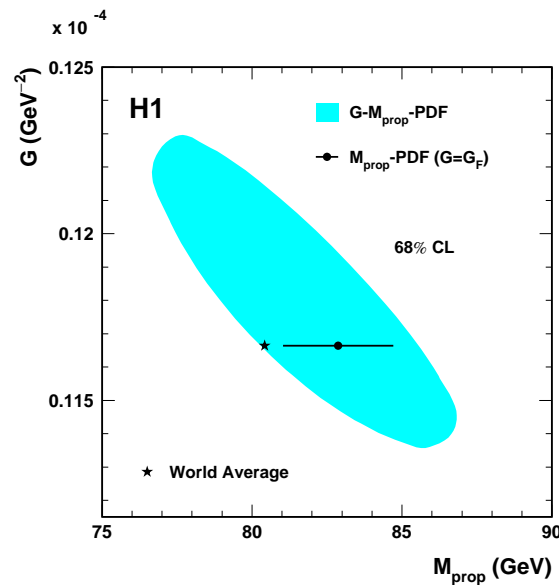
The HERA precision is expected to improve significantly with the data from HERA-II taken at higher luminosity. The longitudinally polarized  $e^\pm$  beams at HERA-II will also provide additional sensitivity in constraining the vector couplings  $v_q$ .



**FIGURE 1.** H1 results (shaded area) at 68% confidence level (CL) on the couplings of  $u$  quark (left) and  $d$  quark (right) to  $Z^0$  in comparison with similar results from CDF (dashed curves) and LEP (full curves).

### 3. Improved $W$ propagator mass measurement at HERA

The cross section data allow a simultaneous determination of the Fermi coupling constant  $G_F$  and the  $W$  boson mass, and of the PDFs ( $G$ - $M_{\text{prop}}$ -PDF fit). When treating  $G$  and  $M_{\text{prop}}$  as independent parameters, the sensitivity on  $G$  and  $M_{\text{prop}}$  originates respectively from the normalization and  $Q^2$  dependence of the CC cross sections. The result of the fit is shown in Fig.2 as the shaded area.



**FIGURE 2.** The result of the fit to  $G$  and  $M_{\text{prop}}$  at 68% confidence level (CL) shown as the shaded area. The world average values are indicated with the star symbol. Fixing  $G$  to  $G_F$ , the fit results in a measurement of the propagator mass  $M_{\text{prop}}$  shown as the circle with the horizontal error bar.

Fixing  $G$  to the measured  $G_F$  value [9], one gets a determination of  $M_{\text{prop}}$ , also shown in Fig.1,  $M_{\text{prop}} = 82.87 \pm 1.82_{\text{exp}-0.16}^{+0.30} |_{\text{model}}$  GeV where the first error is experimental and the second corresponds to uncertainties due to input parameters and model assumptions as introduced in Table 5 in [1] (e.g., the variation of  $\alpha_s=0.1185\pm0.0020$ ). This determination differs from all previous ones in the treatment of the correlation between  $M_{\text{prop}}$  and PDFs and represents the most accurate measurement so far of the CC propagator mass at HERA.

Within the SM, the Fermi coupling constant  $G_F$  is connected with the  $W$  boson mass  $M_W$  through a relation which contains EW radiative corrections including quadratic (logarithmic) dependence on the top quark mass  $m_t$  (the Higgs mass  $M_H$ ). A combined EW-PDF fit in the SM gives

$$M_W = 80.786 \pm 0.205_{\text{exp}-0.029}^{+0.048} |_{\text{model}} \pm 0.025_{\delta m_t} - 0.084_{\delta M_H} \pm 0.033_{\delta(\Delta r)} \text{ GeV} \quad (1)$$

where the measured central value corresponds to using the world averaged values of  $M_Z = 91.1876 \pm 0.0021 \text{ GeV}$ ,  $m_t = 178 \pm 4.3 \text{ GeV}$  and a Higgs mass of  $120 \text{ GeV}$ . The uncertainty on  $M_Z$  has a negligible error on  $M_W$  whereas the uncertainty on  $m_t$  gives rise to the third quoted error on  $M_W$ . Varying  $M_H$  from  $120 \text{ GeV}$  to  $300 \text{ GeV}$  results in the fourth error. The last error is due to higher order radiative correction uncertainties.

Together with the world average value of  $M_Z$  given above, the result obtained on  $M_W$  from Eqn.(1) represents an indirect determination of  $\sin^2 \theta_W$  in the on-mass shell scheme:  $\sin^2 \theta_W = 0.2151 \pm 0.0040_{-0.0011}^{+0.0019}$  where the first error is experimental and the second is theoretical covering all remaining uncertainties in Eqn.(1). The uncertainty due to  $\delta M_Z$  is negligible.

Fixing  $M_W$  to the world average value and assuming  $M_H=120 \text{ GeV}$ , the fit  $m_t$ -PDF gives  $m_t = 108 \pm 44 \text{ GeV}$  where the uncertainty is experimental. The result represents the first determination of the top quark mass through loop effects in the  $ep$  data at HERA.

Again the precision of these determinations will be improved by a large amount as the best sensitivity comes from the CC  $e^-p$  cross section which was measured from a very limited data sample at HERA-I. Polarized  $e^-p$  data corresponding to an increase of one order magnitude in the integrated luminosity from HERA-II are being taken.

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